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The Control of Celery Blights

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THE CONTROL OF CELERY BLIGHTS

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INTRODUCTION

Celery culture is an important part of the vegetable growing industry of Ohio. Between 650 and 700 acres are planted each year which produce a crop with a farm value varying between $300,000 and $350,000, Ray et al. (20). Most of this acreage is situated in the northern half of the state and consists of muck lands and of garden districts suburban to a number of large cities. The crop is often grown on the same land year after year. Some fields have been planted to celery continuously for 20 years, and in many instances two crops are grown each season. This lack of crop rotation, coupled with the fact that the diseased celery refuse is usually left on the ground and plowed under each year, insures the maintenance of plentiful sources of disease inoculum.

Celery in Ohio is subject to three leaf blights. These, in the order of their importance, are known as late blight, caused by *Septoria apii* (Bri. & Cav.) Rostr.; early blight, caused by *Cercospora apii* Fres.; bacterial blight, caused by *Bacterium apii* Jagger. Any or all of these blights are likely to appear somewhere in Ohio every season when weather conditions are favorable for their development.

Individual losses sometimes run as high as 90 per cent, and are frequently from 5 to 50 per cent of the possible yield. A crop which is diseased is not as readily sold as one free from blight and its keeping qualities are impaired. As a result of these reductions in yield, appearance, keeping qualities, and price, it is probable that a monetary loss totalling at least $75,000 is suffered by the celery growers of Ohio during the average year.

DESCRIPTION OF THE CELERY BLIGHT

Late blight.—Late blight *(Septoria apii)* was first noted in the United States about 40 years ago when it occurred in fields in the Atlantic coast area, Chester (3) and Humphrey (12). It has since appeared in areas as widely separated as Michigan, Coons (4); California, Rogers (21); and Bermuda, Ogilvie (19). This disease is especially favored by periods of wet weather with temperatures ranging from 40° to 70° F., Flachs (8) and Thomas (25). It often appears in Ohio fields in July but is seldom severe until late August and during September and October. Heavy applications of manure and nitrate fertilizers result in a succulent vegetative growth which makes the plants more susceptible to late blight infection. Thomas (25) found that plants injured by nematodes were more severely attacked by late blight than those with healthy roots. This has also been observed in Ohio. Kinney (14) working in Rhode Island found that top-dressings of seaweed, manure, or leaves checked infection considerably. In Ohio partially rotted straw and steamed garbage have been used to advantage for this purpose. Other investigators have reported a reduction in disease from the use of lime, gypsum, and Kainit.

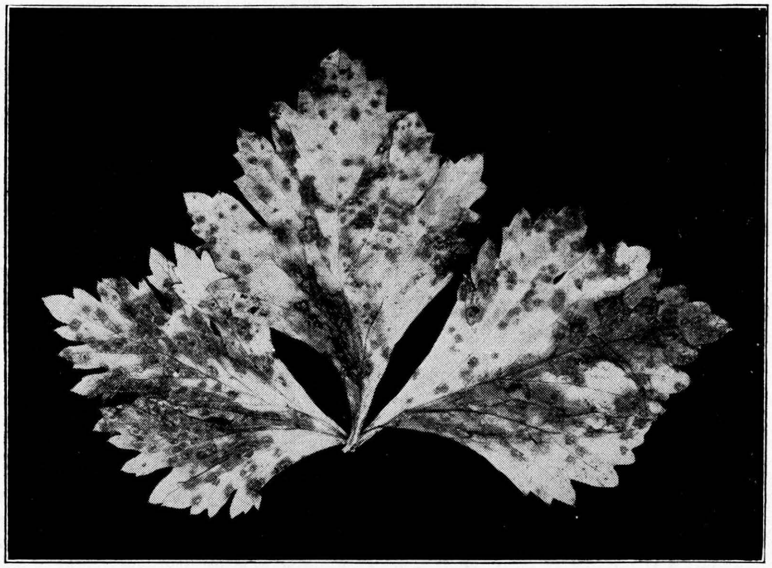

Fig. 1.—Late blight of celery, caused by *Septoria apii*. Note the black pin-point fruiting bodies of the fungus in the lesions of the lower left-hand leaflet

Any portion of the plant above the soil line may be affected by late blight. The first visual indication that the disease is present in a field is the appearance of small, circular, yellowish spots on the leaf blades. These spots, or lesions, soon turn brown and become marked by numerous, minute, black dots, the fruiting bodies of the fungus (pycnidia), Figure 1. When the celery is growing very vigorously these lesions may reach a diameter of about one centimeter before the pycnidia appear.

A pycnidium is shown in diagrammatic cross-section in Figure 2.

The spores produced in these flask-shaped bodies, when mature, are ejected on being wetted and are spread about the field by wind, rain, and cultivation, ready to cause secondary infections if weather conditions remain favorable long enough. The lesions caused by *Septoria apii* become visible in about 10 to 15 days after infection takes place. In cases of severe infection clusters of pycnidia, elongated in outline, may appear on the leaf stalks and petioles. Also, they may occur imbedded in the tissue of the seedcoats, Figure 3. Extensive studies of late blight on celery have been made by Duggar and Bailey (6), Rogers (21), and Thomas (25), and reference is made to their work for further details concerning this disease.

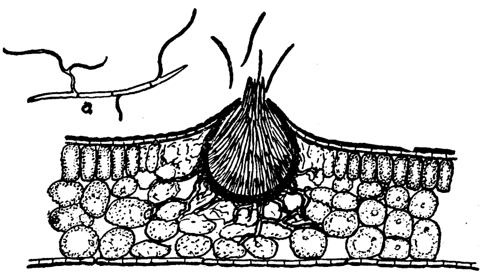

Fig. 2.—Cross-section of pycnidium of *Septoria apii* in celery leaf, enlarged. (a) Single spore germinating. X approx. 400.

Early blight.—The occurrence of early blight of celery *(Cercospora apii)* was reported in the United States several years before that of late blight, Galloway (10) and Halsted (11). It is now widely spread in this country and Europe. It is most common in seasons of high temperatures and high humidities. It is especially favored by dry soil conditions and temperatures above 70° F., Klotz (15), and is checked by short periods below 40° F., Rolfs (22), such as occur during the nights of early fall. The spores of the early blight fungus may germinate and cause infection in the moisture of heavy dews or light rains. They are spread about by rains and cultivation and through the use of manure containing celery refuse. The disease is most common in Ohio in July, August, and September but it seldom causes serious loss.

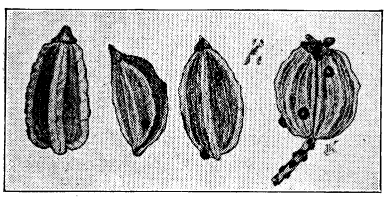

Fig. 3.—Pycnidia of *Septoria apii* imbedded in celery seedcoats. X approx. 25 (After Coons).

Early blight appears first on the outer leaves where small, yellowish-green spots are formed. These lesions enlarge rapidly and are irregular in outline, Figure 4. The affected tissue becomes papery in texture and brown in color, the color later changing to an ashen grey as the fungus begins to produce spores. The margins of these spots are sometimes a dull pink. Lesions in the form of grey streaks may appear on the stems. Infection occurs through the stomata and the disease becomes visible about five to eight days later under conditions favorable to the fungus, Klotz (15). Detailed descriptions of the early blight fungus and its effects on the celery plant have been given by Duggar and Bailey (6), Foster and Weber (9), Galloway (10), Klotz (15), and Kraut (16).

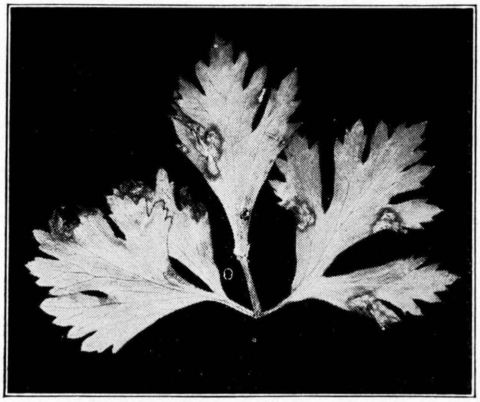

Fig. 4.—Early blight of celery caused by *Cercospora apii*

Bacterial blight.—Bacterial blight *(Bacterium apii)* was found in New Jersey as early as 1892 but did not become common in celery fields until about two decades later, at which time Jagger (13) described it in detail. It now occurs commonly in New York, Indiana, Michigan, Minnesota, and Ohio. It is not found in Ohio as frequently as either late or early blight, altho it usually occurs in some of the fields in northern Ohio each year and may cause considerable loss. It is favored by periods of warm, moist weather, Dye and Newhall (7).

The disease occurs chiefly on the leaf blades where it develops as small, rusty-brown spots with yellowish borders. A leaf infected with bacterial blight is shown in Figure 5.

The lesions usually remain small and seldom cause the death of a leaf. They are distinguished from late blight by their more reddish-brown color and by the absence of the black pycnidia which identify the latter, and from early blight by their smaller size and lack of the ashen-grey mold characteristic of that disease.

OVERWINTERING OF THE CAUSAL ORGANISMS

During years when late blight is prevalent in the celery-seed-growing districts of the United States and France the fungus may become established as pycnidia imbedded in the tissues of the seed-coat, as previously mentioned. Some of the French-grown seed is quite free of the Septoria fungus. The fungus remains viable in the seed for approximately two years and in diseased celery refuse for about 8 to 11 months, Kraut (17).

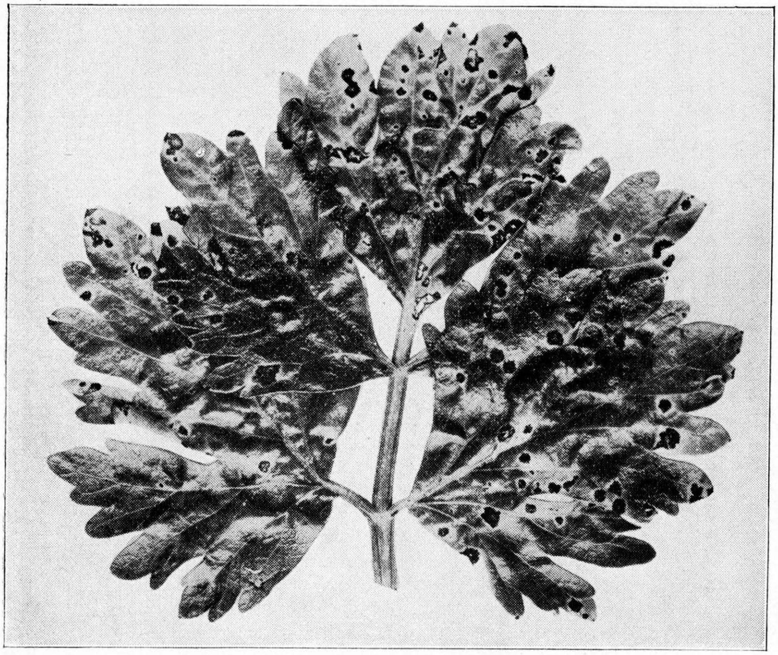

Fig. 5.—Bacterial blight of celery, caused by *Bacterium apii* Note absence of fruiting bodies in the lesions

Early blight is probably seed borne also, but evidence of this is not conclusive. Late in the season the fungus causing this disease forms dense masses of mycelium (sclerotial bodies) in the tissues of the host by means of which it lives over the winter. They are abundant in leaf tissue and in case of a related species of Cercospora have been found in the seedcoat of the host.

It has not been definitely established that bacterial blight is seed borne. However, the fact that the disease often appears on young plants in seed beds, on soil which has not previously grown celery, suggests the possibility that seed transmission does occur. It is known to live over the winter in diseased celery refuse.

WEATHER DATA

Environmental factors, especially those of rainfall, humidity, and temperature exert a very strong influence in determining the severity of the celery blights during any season. Since reference will be made later to the weather conditions during certain seasons, some of the data on rainfall and mean temperatures at Wooster, Ohio, Alexander and Patton (1), are given in Table 1.

TABLE 1.—Rainfall and Mean Temperatures at Wooster, Ohio, from July to October During the Years 1925 to 1928

Year	July		August		September		October		Soil moisture condition at harvest
	Rainfall	Temp.	Rainfall	Temp.	Rainfall	Temp.	Rainfall	Temp.	
	Inches	*° F.*	*Inches*	*° F.*	*Inches*	*° F.*	*Inches*	*° F.*	
1925........	4.09	70.4	1 88	70.4	4.08	67.8	3.01	44.4	Medium
1926........	2.49	71.4	2.75	73.1	8.51	65.2	5.29	52.2	Very wet
1927........	4.28	71.0	2.88	65.6	2.69	66.0	0.90	55.8	Very dry
1928........	3.75	72.7	4.03	72.7	0.65	60.4	2.17	55.6	Dry
Normal....	4.06	71.5	3.55	69.6	3.32	63.7	2.57	51.8	....

From the data in Table 1 it will be seen that the summer of 1925 was an average one in respect to rainfall and temperature. The celery blights were of average severity. The rainfall of July and August, 1926, was somewhat below normal but that of September and October was more than twice the normal amount for those months. There were many cloudy days of high humidity. The soil in many fields became very wet so that spraying and dusting operations were hindered; this was especially true of muck soils. As a result of these conditions late blight became very severe in late October, 1926. The check plots in some of the experimental fields became so badly diseased that the increase in yields obtained by dusting or spraying was as great as 100 per cent in some instances. The fall of 1927 was drier than usual and late blight of celery was very scarce. The check plots in only 4 out of 10 experimental fields located on muck soils were injured significantly. Late blight was slightly more prevalent on very late celery on upland soils during this season. The rainfall during the celery growing-season of 1928 was again below normal and none of the celery blights were severe in Ohio except in isolated instances.

PRELIMINARY CONTROL MEASURES

Seed treatments.—The pathogenes responsible for the celery blights may occur on the seed and cause seedling infection in the seedbed. For this reason seed treatment is sometimes recommended as an aid in controlling these diseases. However, seed treatments thoro enough to kill the late blight fungus in the seed-coats of the celery seed are so severe that they often reduce germination materially. This is especially likely to happen if the seed is old. Seed over two years old is not commonly treated since even *Septoria apii*, the one of the three pathogenes which lives longest, does not remain viable in the seed much in excess of two years, Campanile (2), Coon (4), Flachs (8), and Kraut (17). For this reason the use of seed two or more years old is recommended in some instances as a means of reducing seedling infection. It is interesting to note in this connection that late blight of celery, which was formerly very severe in Bermuda, no longer causes much loss there, presumably due to the governmental restrictions which have been placed on the importation of any celery seed in which the Septoria fungus can be found by microscopical tests.

The following standard seed treatments have been used in combatting celery blight. The seed may be soaked for 30 minutes in a 1-1000 solution of corrosive sublimate (1 ounce to 7.5 gallons of water or 1 tablet to 1 pint of water). This solution should be made up and used in a wooden or earthenware container. Also a 30-minute immersion in a 1-240 solution of formalin in water (1 ounce in 2 gallons of water) has been found to be effective. Another method which is inexpensive but efficient is that of placing the seed in an over-sized bag of some material like cheese-cloth and soaking it in water heated to 48° C. (118° F.) for 30 minutes. The seed should be well rinsed with cold water after any of these treatments and planted while wet. Less injury from seed treatment occurs if the seeds are kept very moist for several days prior to placing them in the fungicidal solutions. Seed may also be treated with any one of a number of the organic mercury compounds now on the market by following the manufacturer's directions.

Seed treatment is not always as beneficial as one might expect and this precaution alone does not insure freedom from seedling infection. The causal organism which the grower is trying to avoid may be present in the soil of the seedbed in which case seed treatment is of little or no use. Only soil which has not previously grown celery and which has had no chance to become contaminated by diseased celery refuse should be used for a seedbed.

Spraying or dusting the seedbed.—Young celery plants frequently become infected by blight while still in the seedbed. The source of inoculum for this early infection may be the seed, the soil, or in some instances diseased plants growing in adjacent plots. It is especially important to have the young plants free from blight when they are set in the field since any which are affected will act as centers from which infection will spread as soon as conditions are favorable for the development of the disease. If blighted plants are transplanted from the seedbed the occurrence of the disease generally over the field may be advanced many days and thus the chances of a severe epiphytotic will be greatly enhanced. From two to four applications of a copper fungicide on the young plants in the seedbed should insure clean plants at the time they are set in the field, Newhall (18). A 20-80 copper-lime dust is more commonly recommended than spray because of the greater ease and convenience with which the former may be applied. The value of seedbed dusting has been demonstrated many times and the results given below are typical of those obtained in many of the tests.

On June 12, 1925, late blight was found in the celery seedbed of a grower near Cleveland. The greater portion of this bed was immediately treated with a dust made up of 20 parts of monohydrated copper sulfate and 80 parts of hydrated lime. A small group of plants was left untreated as a check. Two more applications of this dust were made later at 9-day intervals. The plants from this bed were set in the field early in July. Three rows across the field were set with the untreated check plants. The grower dusted all the plants at regular intervals during the season. On August 26 a count showed that 52 per cent of the plants untreated in the seedbed were blighted while only 3 per cent of those which had been dusted were affected. Not only was the proportion of diseased plants in the check 1700 per cent greater than in the portion of the field set with treated plants but the lesions were many times more numerous on the leaves of the former group. The crop was harvested on September 26. The average trimmed weight of the plants which were not dusted in the seedbed was 0.733 pounds while the treated ones weighed 1.165 pounds, or 60 per cent more than the former.

The results obtained by dusting the seedbed are not always as striking as those given above and tests carried out in dry seasons when blight did not become severe later in the field have sometimes failed to show any gain from applying dust to the seedlings. However, dusting or spraying the seedbed is an excellent form of insurance against loss from blight which may originate there and the practice is earnestly recommended. The first application of dust, or spray if it is preferred, should be made soon after the seedlings are up. Three or four more should follow at intervals such that new growth is kept covered. A final application made just before the plants are removed to the field is an added protection. To be most effective the dusting should be done while the plants are moist, either from dew, rain, or artificial watering. In May and June the evening has been found the most satisfactory time of day to apply the dust. The use of a bordeaux spray or dust on the plants in the seedbed has also been found to check damping-off in some instances.

BLIGHT OFTEN WORSE ON OLD TRANSPLANTS

Since the celery seedbed is always a potential source of blight, the seedlings should not be left in the bed longer than is necessary after they have reached a proper size for transplanting. The crowded plants soon form a dense mass of foliage thru which air cannot circulate and as a result an excessively humid condition is maintained about the leaves. Many of the seedlings become diseased during periods of damp weather.

The detrimental effect which may result from leaving the plants in an outdoor seedbed beyond the normal time for transplanting was observed in two instances near Cleveland in 1927. The rainfall for July of that year was above normal and the greater portion of it occurred during the latter half of the month. One grower removed part of the plants from his seedbed and set them in the field on July 14. Those remaining were transplanted about two weeks later. On October 13 those plants which had been removed from the seedbed during the last few days in July showed 20 times as much blight as those set on July 14. In another field plants which were removed from the seedbed at the proper growth stage were found to be almost free of blight while another group taken out 10 to 14 days later averaged 248 lesions per plant on October 13. In each of the instances cited above the plants which remained in the seedbed over the longer period were infected with blight at the time they were set in the field.

MULCHES AND SOIL-BORNE BLIGHT

It has frequently been observed, by growers and investigators alike, that mulches of various kinds may act as a partial control of celery blight when placed between the rows in the field. The mulch covering confines many of the blight spores to the soil beneath it and as a result they are not as easily distributed about the field by wind and rain. In Ohio it is a common practice for growers of upland celery to mulch their fields. This is particularly true near Cleveland where steam-treated garbage waste is available in large quantities. Manure, straw, leaves, and paper have been used also.

Table 2 shows the effect of heavy mulches of garbage and manure applied soon after the plants were set in the field upon the subsequent development of late blight. Mulching in this case reduced the blight to about 24 per cent of that occurring on the checks.

TABLE 2.—Effect of Mulching upon Late Blight Development on Upland Celery

Field	Treatment	Average number of blight lesions per plant		Percentage of control due to mulch
		Mulch	No mulch	
1	Garbage (50 tons per acre)	84	288	70.8
2	Garbage (50 tons per acre)	156	574	72.8
3	Manure (20 tons per acre)	88	612	85.6

The fields listed in this table had been planted to celery nearly every summer for a number of years and the soil was evidently highly contaminated with the causal organism of late blight. The whole of each field was consistently dusted for blight control during the period of the experiment. Some growers consider manure to be a better mulch for blight control than garbage but this has not proved to be true in a number of instances where actual counts of the relative number of diseased plants in areas mulched with these two materials have been made.

During the summer of 1927 an experiment was carried out to determine the possibility of controlling late blight of celery by the use of a paper mulch, by a covering of straw, and also copper sulfate and mercuric chloride applied to the soil while the plants were small. A muck area near Ravenna, Ohio, was selected for the test. The plots were one-eightieth of an acre in extent and the treatments were duplicated. The materials were applied July 10, at which time transplants had just started growth after being set in the field. The results are shown in Table 3.

TABLE 3.—Effect of Paper and Straw Mulches and Two Chemicals on the Control of Late Blight of Celery on Muck

Treatment	Rate of application per acre	Reduction in blight compared to check
Paper mulch—asphalt coated	Strips 3 feet wide	70 per cent
Straw mulch—partially rotted	Layer 3 inches thick	50 per cent
1-10 copper sulfate crystals—water	2800 gallons	Very little
20-80 monohydrated copper sulfate—lime	800 pounds	Very little
40-60 monohydrated copper sulfate—kaolin	400 pounds	Very little
1-50 mercuric chloride—water	2400 gallons	Very little
1-15 mercuric chloride—kaolin	600 pounds	Very little

The paper mulch was placed close to the plants so that only a very small area of soil was left exposed in this plot. A small area of soil was left untreated around each plant in the plots treated with mercuric chloride and copper sulfate. The 400-pound application of a 20-80 copper-lime dust was approximately equivalent to the total amount necessary to dust an acre of plants thruout the season.

The plants were rather severely injured by the copper sulfate-kaolin treatment and slightly checked by the mercuric chloride-kaolin. The injury was only temporary in each case, however, and the plants were nearly normal at the end of the season. None of the chemical treatments reduced the amount of blight materially, as compared with that which occurred on the check plots. This indicates that this form of treatment, which involves the killing of the causal organism in the surface layer of soil, is not a practical means of checking later infection. The straw mulch reduced blight about one-half but necessitated the pulling of many weeds by hand. The paper mulch not only checked blight and the weeds more effectively than any of the other treatments used in this test but the plants growing under it were at least one-third larger than those in the remainder of the field. This was probably due to a soil moisture conservation by the paper covering during the very dry August and September of 1927. These results indicate that steam-treated garbage, manure, and paper are of value as mulches to control, or greatly check, celery blight.

FIELD EXPERIMENTS

Methods and materials.—Many materials have been tested in the course of this investigation on field plots to determine, if possible, their efficiency in controlling celery blights. The experiments were conducted over a period of four years and in several different localities in the northern half of Ohio. Celery had been continuously grown for a number of years in most of the test fields.

Dusts were applied principally with hand-operated dusters and the work was done in the early morning while the plants were wet with dew unless otherwise stated. Hand dusters are comparable to power machines in efficiency if properly operated, but they often apply more dust per acre than the latter. This is especially true if both sides of the row are dusted as was the practice after the plants became large in these experiments. The liquid sprays were also applied with hand-operated equipment in most instances. Small sprayers do not compare as well with power-driven machines as is the case with dusters since the pressures which can be maintained with hand sprayers are usually very low.

The spray materials were always prepared just before they were to be used. The dust used most was one made by thoroly mixing 20 parts by weight of monohydrated copper sulfate with 80 parts of fresh hydrated lime. A few tests were made of dusts in which the copper content was varied from that mentioned above and still others in which part of the lime was replaced by other materials like kaolin and infusorial earth. Most of the commercial dusts used had a copper content similar to that in the 20-80 copper-lime mixture. The bordeaux sprays were all of the 5-5-50 formula (5-7½-50 if hydrated lime was used), but in some instances other materials were added to this as a base.

The plots were arranged to give duplicate or triplicate tests of each material whenever possible. The plots always included either three or four rows of celery, only the center rows of which were used in making counts or determining yields. Most of the experiments were on the late celery crop and the data presented deal with late blight *(Septoria apii)*, unless otherwise stated. Early blight and bacterial blight became severe only in isolated instances. Approximately half of the tests were made on muck and the remainder on upland soils.

Spraying versus dusting.—Ever since the practice of using fungicides as dusts to replace liquid sprays became common the relative efficiency of the two methods has been a moot question. It was possible to compare the fungicidal efficiency of a 20-80 copper-lime dust with that of a 5-5-50 bordeaux spray in nine different instances during the progress of the tests reported here. These experiments were conducted during three different years. In only one case was such a comparison the sole purpose of the experiment. The data in Tables 4 and 5 give a resumé of the results in those experiments which included these two treatments.

The data given in Table 4 represent the average of four tests, all on upland celery, two of which were made in 1927 and one each in 1925 and 1926. The spray gave better results than the dust in one experiment, in another they were very simliar, while in the remaining two the dust gave the better control. When the average of all the tests is considered (as shown in Table 4) the dust increased the yield slightly more than the spray. In another experiment, conducted in 1926, in which only the untrimmed weights from the different plots were determined, the spray increased the yield over its check 53 per cent while the dust gave an increase of 52 per cent.

TABLE 4.—Average Increase in Yield Over Check Plots From Use of 5-5-50 Bordeaux Spray and 20-80 Copper-lime Dust (5 Applications)

Treatment	Yield per acre of trimmed celery	Yield increase over check
	Pounds	*Per cent*
Check	22,600	....
Spray	32,570	44.1
Dust	33,100	46.4

Table 5 represents the average of the results obtained in four different experiments. Two of these were made in 1926 and two in 1927. Two were on upland celery and two on the muck crop. Spray gave the better control of blight in three instances while the dust was more efficient in the remaining one. The percentage of control given in the last column of Table 5 was determined by considering the average number of lesions per plant in the check plot as 100 per cent infection and dividing this number into the difference between it and the number of lesions per plant on the treated plots. This method is used in all of the following tables for calculating the percentage of control.

TABLE 5.—Relative Control of Late Blight of Celery by the Use of a 20-80 Copper-lime Dust and a 5-5-50 Bordeaux (5 Applications)

Treatment	Average number of blight lesions per plant	Percentage control on basis of blight on check
Check	2,495	....
Dust	314	87.4
Spray	231	90.8

On the basis of the data given in Table 5 one would consider spraying to be somewhat better than dusting. However, when both tables and the single instance given are considered together there seems to be little to choose between the 20-80 copper-lime dust and the 5-5-50 bordeaux spray as treatments for controlling late blight of celery. Coons, Nelson, and Walker (5) came to much the same conclusion in tests made in Michigan in which they compared a 20-80 dust with a 5-5-50 spray. It is likely that the comparison would be the same for the early and bacterial blights of celery. Of course, one must consider the fact that the above tests were carried out with the use of hand-operated equipment and under conditions which were very favorable for applying the materials, especially the dust, also that rather large quantities of dust were used in the upland celery experiments, as much as 75 pounds per acre per application in many instances.

Whether a grower should dust or spray is largely a matter of personal preference, modified by such conditions as the size of his planting, the availability of water, the amount of time at his disposal, etc. Small fields of an acre or less can be best treated with a hand duster. Larger areas may be either dusted or sprayed but for anything over two or three acres the use of power equipment is usually most desirable because of the saving in time. If water is not plentiful and close to the field, the labor involved in obtaining it may militate against the use of spray. The fact that dust should be applied only in late evening or early morning when the plants are damp and the wind is low, while spraying is feasible at nearly any time except during high winds, is in favor of the latter method. Probably the average grower can control celery blights more thoroly by spraying than by dusting but he must consider whether the time saved in dusting as compared with spraying is not as valuable as any increase in control which he may obtain by spraying.

Possible substitutes for the 5-5-50 bordeaux mixture and the 20-80 copper-lime dust.—The fungicides most commonly used in Ohio for the control of celery blights are a 5-5-50 liquid bordeaux and a freshly mixed 20-80 monohydrated copper sulfate-hydrated lime dust. A number of commercially prepared copper-lime dusts similar to the above formula are also popular. Similar spray and dust preparations are used in many celery growing districts in this and other countries for the control of blight, Dye and Newhall (7), Foster and Weber (9), Jagger (13), Klotz (15), Kraut (16), Ogilvie (19), and Rogers (21). Sulfur dusts and lime-sulfur sprays have never given satisfactory control of celery blight since sulfur is not very toxic to the causal organisms involved.

A number of mixtures and compounds were compared, in regard to relative efficiency in blight control, with the 5-5-50 bordeaux mixture and the 20-80 copper-lime dust. Various compounds to act as stickers were added to a 5-5-50 bordeaux as a base but were not found to increase control materially. Also several different compounds containing copper were tested as dusts. None of these gave results sufficiently better than the 20-80 copper-lime dust to justify continuing with them. The materials tested and the results obtained are given in Tables 6 and 7.

TABLE 6.—Comparative Efficiency of Various Compounds in Controlling Late Blight of Celery

Location	Treatment	Approximate copper content	Number of blight spots per plant	Control	Yield per acre	Increase in yield over check
		Per cent		*Per cent*	*Pounds*	*Per cent*
Cleveland, 1925	Check	...	837	...	...	...
	Sander's Blue dust	6.0	707	15.5	...	...
	Sulfur dust	...	687	17.9	...	...
	20-80 copper-lime	7.0	403	51.9	...	...
	Copper carb.+lime (1-1)	9.0	223	73.4	...	...
	Copper carb.	18.0	196	76.6	...	...
Cleveland, 1926	Check	...	...	...	43,000	...
	Colloidal copper+lime	4.0	6412	35.8	51,000	16
	Copper stearate	9.0	2560	60.0	64,000	50
	Copper carb.+lime (1-1)	9.0	2284	64.4	64,000	50
	20-80 copper-lime	7.0	455	92.9	74,000	74
Shreve, 1926 (Early blight)	Check	...	...	...	12,730	...
	Copper stearate	9.0	...	...	16,510	29.7
	20-80 copper-lime	7.0	...	...	27,690	117.5
Willard, 1926	Check	...	250	...	...	...
	Copper stearate	9.0	224	10.4	...	...
	20-80 copper-lime	7.0	175	30.0	...	...
Willard, 1927	Check	...	2946	...	25,770	...
	Copotex	...	893	70.0	34,702	35.8
	20-80 copper-lime	...	261	91.0	37,680	46.2
Willard, 1928	Check	...	1540	...	22,845	...
	25-75 copper sulfate crystals-lime	7.0	710	53.9	24,684	8.1
	20-80 copper-lime	7.0	260	83.2	30,782	34.7

The data in Table 6 indicate that none of the substitute materials were any better than the standard 20-80 copper-lime mixture. Sulfur as a dust gave very poor control. Kolodust and lime-sulfur were given a two-year trial but were quite ineffectual. Copper carbonate used as a dust gave results comparable to the 20-80 dust, but its copper content is high and it does not seem to adhere as well. Also the mixture as used was expensive. Colloidal copper added to lime was of little value. "Copotex", a commercial dust, was not as good as the ordinary copper-lime dusts in the three trials it was given. Copper stearate was not effective in controlling late blight in most of the cases where it was tested. Copper sulfate crystals were ground very fine after mixing them with an equal weight of infusorial earth. Hydrated lime was then added to this in sufficient quantity to give a final product containing seven per cent of metallic copper. Its control of late blight was not at all comparable to the 20-80 dust.

The addition of oils to a 5-5-50 bordeaux mixture as a base did not materially increase the efficiency of the bordeaux even though they seemed to increase adhesiveness. Neither colloidal copper nor copper hydroxide used as a spray gave as good control as the 5-5-50 bordeaux mixture. Thus, on the basis of the data given in Tables 6 and 7 none of the materials listed may be expected to replace a 5-5-50 bordeaux spray or a 20-80 copper-lime dust as standard treatments for the control of celery blights.

TABLE 7.—Comparative Efficiency of Various Copper Fungicides in the Control of Late Blight of Celery, Cleveland, 1926

Treatment	Approximate copper content	Average number of spots per plant	Control over check
	Per cent		*Per cent*
Check (A and B)	....	2947	....
A. Dusts			
Colloidal copper + lime	4.0	1218	58.7
Copper carb. + lime	9.0	655	77.8
Copper stearate	9.0	652	77.9
20–80 copper-lime	7.0	469	84.1
B. Liquids			
Colloidal copper	0.2	1385	53.0
Copper hydroxide	0.2	1344	54.5
Bordeaux (5–5–50)	2.5	323	89.1
Bordeaux + 2% "Volck" oil	2.5	217	92.7
Bordeaux + 2% "Scale Proof" oil	2.5	209	92.9
C. Liquids			
Check	....	2688	....
Bordeaux 5–5–50	2.5	55	98.8
Bordeaux + 2% "Volck" oil	2.5	55	98.8

Freshly-mixed versus commercial dusts.—Several comparisons have been made in this investigation in an effort to determine the relative efficiency of copper-lime dusts freshly mixed before using and those purchased from commercial concerns and held in air-tight containers until they were applied. Coons, Nelson, and Walker have described a similar test made in Michigan (5). The copper and lime are perhaps more intimately mixed in the commercial product than is the case with the freshly prepared dust but the former usually has the disadvantage of standing about for long periods before use. Just what changes may take place when copper and lime are in contact in tightly sealed cans are not definitely known, but if these cans are opened and partially emptied and not properly closed afterward, it seems certain that the dust mixture deteriorates rather rapidly. When hydrated lime, either in sacks or mixed with copper in cans, becomes carbonated through exposure to the air it forms an inferior bordeaux when wetted in the presence of copper. Thus the hydrated lime used in making a freshly mixed copper-lime dust should be of recent manufacture. It is good practice to place the lime in cans which may be sealed against air if it is to be held over long periods before using. Table 8 shows the results of some of the tests made in comparing the commercial and freshly-mixed dusts for efficiency in blight control.

TABLE 8.—Comparative Efficiency of Freshly-Mixed and Commercial Brands of Copper-lime Dust in Controlling Late Blight of Celery (7 Applications)

Location	Treatment	Blighted leaves per 100 ft. of row	Control	Yield per acre	Increase in yield over check
			Per cent	*Pounds*	*Per cent*
Willard, 1927	Check	2946	....	25,770	....
	20–80 freshly-mixed	261	91	37,680	46.2
	710 commercial	323	89	37,026	43.7
	S–11 commercial	344	88	35,428	37.5
	D–6 commercial	379	87	35,938	39.4
Shreve, 1927	Check	1677	....	29,410	....
	20–80 freshly-mixed	217	87	43,170	50.2
	D–6 commercial	284	83	39,385	33.9
	S–11 commercial	301	82	42,800	45.5
Ravenna, 1927	Check	1660	....	25,845	....
	20–80 freshly-mixed	101	94	36,300	40.4
	S–11 commercial	122	93	35,429	37.1
	D–6 commercial	138	92	36,880	42.7

In nearly every instance, both in the tests cited in Table 8 and in others not included here, the freshly-mixed dust gave slightly better control than the commercial product. Also, the home or freshly-mixed dust is considerably cheaper, as is shown in another section of this paper. The labor involved in mixing is not very great and suitable equipment is not costly. Any form of closed box or drum, with cleats fastened to the inside, which may be rotated is satisfactory. A barrel churn is very efficient. Specially constructed drums are now available which are very useful in mixing a variety of compounds. Some of the power-operated dusters now on the market are equipped with hoppers in which the dust is mixed before and during application. The container of a mixing device should not be filled to more than one-half its capacity. Turning at a moderate rate for a period of five minutes should then give a sufficiently thoro mix. Only enough dust should be made up each time to cover the area to be dusted, unless cans which may be tightly closed are available in which an excess amount may be stored. The stock supply of monohydrated copper sulfate, which takes up water readily, should also be kept in an air-tight receptacle.

TABLE 9.—Comparative Efficiency of a Number of Copper Dusts in Which Part of the Lime in a 20-80 Copper-lime Dust Was Replaced by Other Materials (6 Applications)

Location	Treatment	Blighted leaves per 100 ft. of row	Control over check	Yield per acre	Increase in yield over check
		Number	*Per cent*	*Pounds*	*Per cent*
Willard, 1927	Check	2946	....	25,770	....
	20-80 Cu-L	261	91	37,680	46.2
	20-60-20 Cu-L-K	287	90	36,082	40.0
	20-60-20 Cu-L-I. E.	573	81	36,445	41.4
Ravenna, 1927	Check	1660	....	25,845	....
	20-40-20-20 Cu-L-K-I. E.	81	95	39,350	44.5
	20-80 Cu-L	101	94	36,300	40.4
	20-40-20 Cu-L-K	146	91	36,445	41.0
Shreve, 1927	Check	1677	....	29,410	....
	20-60-20 Cu-L-K	190	89	41,420	44.2
	20-80 Cu-L	217	87	43,170	50.2
Lodi, 1927	Check	298	....	....	....
	20-80 Cu-L	22	92	....	....
	20-60-20 Cu-L-K	32	89	....	....
	20-60-20 Cu-L-I. E.	38	87	....	....
Willard, 1928	Check	1540	....	22,845	....
	20-80 Cu-L	260	83.2	30,782	34.7
	20-50-30 Cu-L-K	280	81.8	28,136	23.2
	20-50-15-15 Cu-L-K-I. E.	340	77.9	29,152	27.6
	20-50-30 Cu-L-I. E.	422	72.6	26,845	17.5

Note: Cu represents monohydrated copper sulfate; L, lime; K, kaolin; and I. E., infusorial earth.

The substitution of other materials for part of the lime in a 20-80 copper-lime dust.—The lime contained in a dust made by mixing 20 parts of monohydrated copper sulfate with 80 parts of hydrated lime is greatly in excess of the amount necessary to prevent copper burning of celery foliage. Since the lime is in excess, it seems possible that some of it might be replaced by some inert material which would give the resulting mixture greater spreading or adhesive qualities. With this in mind certain proportions of the lime were replaced by kaolin or infusorial earth, or by a combination of the two products. The resulting mixtures were compared with the standard 20-80 dust in several experiments conducted during the summers of 1927 and 1928. The results are shown in Table 9. Similar comparisons have been made on potatoes by Tilford (27).

The replacement of 25 per cent of the lime in a 20-80 copper-lime dust by kaolin to give a 20-60-20 mixture resulted in a rather heavy dust which did not flow thru a hand duster as well as that of the 20-80 formula. When infusorial earth was substituted for kaolin in an equal proportion the resulting mixture passed thru the duster very well but was somewhat too bulky in proportion to its weight (see the last section of this paper). The 20-50-15-15 formula tested at Willard in 1928 was the best substitute mixture used from the standpoint of its flowing qualities. The data of Table 9 indicate that the use of either kaolin or infusorial earth to replace part of the lime in a 20-80 copper-lime dust does not provide a mixture which is materially superior to the standard formula for blight control. Since each of the materials costs more than hydrated lime their use in preference to the latter is not recommended. The plots dusted with any of the mixtures containing kaolin usually appeared, one week after dusting, to have more residue remaining on the leaves than those dusted with the 20-80 copper-lime dust. The kaolin itself does adhere to the leaves very well, but dusts of which it was a part did not prove to be any more efficient in blight control than the 20-80 mixture.

TABLE 10.—The Relation Existing Between the Copper Content of a Dust and Its Efficiency in Controlling Late Blight of Celery

Treatment	Approximate copper content	Number of blight spots per plant	Percentage of control on basis of check
1925	*Per cent*		*Per cent*
Check	....	837	....
20-80 Cu-L	7.0	402	51.9
25-75 Cu-L	8.2	255	69.5
30-70 Cu-L	10.0	190	77.3
Copper carbonate + lime (1-1)	9.0	223	73.4
Copper carbonate	18.0	146	82.6
		Yield per acre of trimmed celery	Increase in yield over check
1927		*Pounds*	*Per cent*
Check	....	20,835	....
Av. 2 com'l. dusts	7.0	27,700	32.9
40-60 Cu-L	14.0	29,308	40.6

The copper content of a dust as related to its effectiveness in blight control.—The relation between the copper content of a dust or spray and its effectiveness in controlling celery blight has not been very thoroly investigated in the experiments reported here. Tilford (26) and others have made extensive comparisons in relation to potato diseases. No tests of dusts containing less than seven per cent of metallic copper have been made but the results of two in which mixtures were included with this as the minimum amount are included in Table 10.

Increasing the copper content did result in better blight control and larger yields in these tests. However, when the extra cost involved is considered, the use of a dust containing a metallic copper content in excess of seven per cent hardly seems justified.

Dusting at different times of day.—Emphasis is always placed on the point that celery should be dusted only when the foliage is wet with dew, or some other form of moisture, and when the air is quiet. These conditions most often exist in the early morning or late evening. The dust not only adheres to the foliage better with a film of moisture present but the copper sulfate and lime quickly unite to form the colloidal membrane of a bordeaux. This not only checks the carbonation of the lime particles but the materials will adhere to the leaf much more tightly after the film dries than will the dust particles as such. If the air is quiet the dust may be more easily directed against the leaves. Also the dust particles may drift about close to the ground for a time instead of being quickly blown upward and away, thus more of the material will have an opportunity to come in contact with the celery foliage.

During the season of 1928 a series of plots was dusted at different times thruout the day to determine the resulting variations in efficiency of blight control. Seven applications of a 20-80 copper-lime dust were used. Three plots were dusted in the early morning when the plants were covered with dew, three in the evening after the wind had ceased and dew was just forming, and three others at noon when the foliage was dry and air movement was usually noticeable. The results are shown in Table 11.

TABLE 11.—Relative Efficiency of Dust Treatments Made at Different Times During the Day (7 Applications)

Treatment	Blighted leaves per 100 feet of row	Control over check	Yield per acre of trimmed celery	Increase in yield over check
20-80 Copper-lime dust:		*Per cent*	*Pounds*	*Per cent*
Morning application	260	83.2	30,782	34.7
Night application	355	77.0	26,717	17.0
Noon application	773	49.8	24,722	8.2
Check	1540	....	22,845	....

These results show that, on the basis of both yield increase over the check and lessened number of diseased leaves, the morning applications were much more efficient in blight control than those made either in the evening or at noon. Evening was found to be a better time for dusting than noon. The noon applications did not give a satisfactory control and were almost a total loss of time and material. Dusting may be done to the best advantage in the early morning between daylight and about 8:30 A. M. If it is impossible to cover the field by utilizing all of the favorable mornings, then the remainder should be finished in the late evening or even at night but never during the day while the plants are dry and the wind is blowing. In seedbed dusting in May and June advantage may be taken of the long quiet evenings but in August and September conditions favorable for dusting are more frequently met with in the morning.

Not only should the dust be applied under favorable conditions but applications of either dust or spray should be timed at proper intervals. A definite control program should be followed. The treatments should begin early in the life of the crop and be made frequently enough to keep the new growth well covered. The time intervening between applications is regulated largely by growth conditions and the amount and frequency of rain. If the weather is damp and cloudy the plants should be kept well covered with the fungicide but in hot, dry periods infection is much less likely to occur. Applications are more effective if made ahead of rainy periods than following them and the approach of such periods can frequently be determined far enough in advance so that the plants may be protected.

A POSSIBLE RELATION OF DEGREE OF LIGHT INTENSITY AND PERIOD OF LEAF WETTING TO BLIGHT INFECTION

Duggar and Bailey (6), Galloway (10), and Townsend (28) all found that shading the celery plants reduced infection by early blight. Sturgis (24) noted that etiolated (blanched) plants were very susceptible to late blight infection. It was observed by the authors in a number of instances that the leaves on the north side of plants in rows running east and west were more severely blighted. Actual counts were made in one instance and the data are given in Table 12.

TABLE 12.—Relative Amount of Late Blight on the North and South Sides of Celery Rows

Plot	Number of blighted leaves per 100 feet of row		Excess of north over south side
	North side	South side	
			Per cent
Check	1120	1826	63.0
Average of 8 treated plots	204	295	44.5

These results show that there was nearly 50 per cent more blight on the north side of rows planted east and west. This indicates that infection by late blight is favored by the presence of moisture on the leaves. The surface of the leaves on the north side of the row remains wet somewhat longer each morning and also the air in immediate contact with them is probably more moist than that around those on the south side at all times when the sun is shining. The effect of light may be one of inhibiting germ tube development or only the indirect one of drying the foliage more quickly on the south side of the row.

RELATIVE COST OF SPRAYING AND DUSTING

The question is often asked, "What does it cost per season to spray or dust an acre of celery?" Dye and Newhall (7) in New York in 1924 estimated the cost to spray (seven applications) at $12.00 per acre and to dust at $14.00 to $20.00, depending on whether the home-mixed or commercial product was used. Stirrup (23) in England in 1927 estimated the cost of eight applications of spray at $15.00 per acre. Weber (29) found that in Florida the cost of dust, applied in sufficient quantities to equal a bordeaux spray in blight control efficiency, was prohibitive.

If two men and a team can spray two acres per hour and the time of the man is worth $4.00 per day and that of the team $6.00, the labor cost per acre to spray will be about $0.75. Granted that one man and a team can dust 3 acres per hour, the labor cost of dusting will be about $0.40 per acre. With hydrated lime at one cent per pound and crystal copper sulfate at eight cents, the materials for enough bordeaux mixture to spray one acre (100 gallons) will cost $1.65 per application. If monohydrated copper sulfate costs sixteen cents per pound, a 50-pound application of a commercial dust selling at $7.00 per hundred pounds would cost $3.50. On the basis of the values assigned above for labor and materials the cost per acre for seven applications of spray and freshly-mixed or commercial dust would be as shown in Table 13.

TABLE 13.—Relative Cost of Spraying or Dusting an Acre of Celery With Seven Applications of Material

Items	Spraying	Dusting	
	5-5-50 Bordeaux	Freshly-mixed	Commercial
Labor	$ 5.25	$ 2.80	$ 2.80
Materials	6.30	14.00	24.50
Total	$11.55	$16.80	$27.30

The costs as computed above should include a depreciation charge on equipment. This will vary for different growers according to the acreage treated each year, but it should average about $5.00 per acre per year. Since the price of spraying and dusting equipment is very similar, this item is much the same for each method. The depreciation charge is less in the case of hand-operated equipment, but the labor cost is greater. Thus, the figures as given above are probably representative of average conditions and indicate that spraying can be done more cheaply than dusting, and also that the practice of using a home-mixed dust reduces the cost materially below that for commercial brands.

THE RATE AT WHICH DIFFERENT TYPES OF DUSTS PASS THROUGH A HAND DUSTER

It was frequently noted while applying the different dust mixtures used in many of the preceding experiments that all of them did not flow thru the duster in the same way or at the same rate. Accordingly, four quite different dusts were selected and trial applications made. The results are shown in Table 14.

TABLE 14.—Rate of Flow of Different Dusts Through a Hand Duster

Materials	Copper content	Application per acre	Metallic copper content applied per acre
	Per cent	*Pounds*	*Pounds*
Copper stearate plus lime (3-1)	9.0	26.2	2.4
Copper carbonate plus lime (1-1)	9.0	78.0	7.0
Copper-lime (20-80)	7.0	73.7	5.2
Colloidal copper plus tuscan clay (1-2)	4.3	99.3	4.2

The copper stearate is of a fluffy yet gummy consistency and does not pass thru a hand duster in the same manner as the heavier and less adhesive lime or kaolin (clay). The two mixtures containing lime were found to flow thru at about the same rate; while the clay, which is considerably heavier than lime, passed thru in about the same volume but greater weight. In using the mixtures given in Table 9 it was found that a given weight of dust containing infusorial earth passed thru the duster more slowly than lime and copper alone, while those with kaolin flowed thru too fast. By mixing the kaolin and infusorial earth in equal parts in a dust made up of 20 parts of monohydrated copper sulfate, 50 parts of hydrated lime, 15 parts of kaolin, and 15 parts of infusorial earth a product was obtained which closely resembles a 20-80 copper-lime dust in flowing qualities and was very satisfactory from the standpoint of ease of application. The way in which a dust mixture passes thru the dusting machine is important and must be considered when adjusting the equipment to apply the proper amount of material.

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SUMMARY

1. Celery in Ohio is subject to three leaf blights: late blight caused by *Septoria apii*, early blight caused by *Cercospora apii*, and bacterial blight caused by *Bacterium apii*.

2. The causal organisms of all the blights live over in the soil in diseased celery refuse, and the lack of crop rotation which exists in celery fields thus insures a plentiful source of disease inoculum each year.

3. Long periods of rainy weather are favorable to each of the celery blights and their severity each season is chiefly regulated by weather conditions.

4. Only late blight causes severe crop losses consistently in Ohio. Early blight is often present but seldom decreases yields materially while bacterial blight occurs infrequently and seldom causes serious loss.

5. Seed treatment and the use of seed two or more years old may keep seedling infection at a low point if the seed is sown in disease-free soil, but cannot be depended upon to keep a crop free of blight after it is set in the field.

6. Spraying or dusting the seedbed several times is earnestly recommended because seedlings should be free of blight when transplanted; otherwise all infected plants act as centers from which infection spreads as soon as weather conditions become favorable for the disease.

7. Seedlings should not be left in the crowded condition existing in a seedbed longer than is necessary since infection may become severe there in spite of all precautions.

8. Mulches of garbage, rotted straw or manure, and paper are effective agents in reducing the amount of blight. Treatment of the soil between the celery rows with copper sulfate or corrosive sublimate did not check blight materially.

9. Spraying with a 5-5-50 (5-7½-50) bordeaux mixture and dusting with a 20-80 monohydrated copper sulfate-hydrated lime dust were found to be practically equally efficient methods of celery blight control. If any advantage existed of one over the other it was in favor of the liquid treatment.

10. The addition of oil spreaders to bordeaux mixture did not materially increase its efficiency in blight control. No other dust mixture tested in which the copper was present in a form different from monohydrated copper sulfate was found to be as effective as the standard 20-80 copper-lime dust.

11. Freshly-mixed dusts (20-80 formula) were found to be slightly more effective in controlling celery blight than similar commercial mixtures in nearly every instance.

12. The substitution of part of the lime in a 20-80 copper-lime dust by inert materials such as kaolin and infusorial earth did not produce mixtures more efficient than the standard formula, but variations in flowing and adhesive qualities were observed.

13. Increasing the metallic copper content of a dust over the usual seven per cent was found to increase the fungicidal efficiency somewhat, but the use of the more costly formulae in preference to that containing only seven per cent of copper was not shown to be worth while.

14. Dusting in the early morning while the celery foliage was very damp was found to give better blight control than applications made in the evening or at noon. Evening proved to be a much more favorable period than noon. Material applied at the latter time was practically wasted.

15. The leaves on the north side of celery rows planted in an east and west direction were found to be more severely infected with late blight in many instances than those on the south side of the plants. This suggests the existence of a relation between light intensity and the period over which the leaves remain wet and the degree of infection.

16. The cost for labor and materials necessary to spray an acre of celery (7 applications) is less than that to dust but the latter method may often be the more desirable because of the sav-

ing in time and labor which it affords. In the case of small areas where power outfits are out of the question, dusting is the more satisfactory method.

17. The amount of any dusting material applied per acre with a hand duster depends largely upon the character of the ingredients since this determines the rapidity and ease with which they flow thru the machine.

18. It is the authors' opinion that emphasis should be placed on the matter of keeping new growth adequately protected with timely applications ahead of rain periods, rather than on the use of stickers, dusts of high copper content, lime-substitute fillers, and mulches.

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